Design of dual resonant frequency Microstrip antennas using the method of experimental design

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1. Introduction

Microstrip antennas (MSAs) are widely used to many kinds of application because the configurations are small, light, and simple, and suitable for mass-production. However, the MSA has a disadvantage of narrow bandwidth.

One of the methods to realize wide frequency band antennas is to increase the number of configurational parameters by using multi-layer structure. However, as the number of parameters increases, the design becomes complicated, necessitating to spend much working time and cost. It is desirable, therefore, to reduce the number of times of calculation and experiment by applying some efficient optimization method to several important parameters chosen out of many configurational parameters. Genetic algorithm is now popular as an efficient method for coping with this type of multiparameter problems[1]. However, this algorithm is very sophisticated, and moreover does not always give global optimum.

This paper introduces a very simple and steady method, a method of experimental design[2],[3], which is applied to the design of MSA with three-layer configurations. It is proved that this method works very effectively in reducing the number of times of calculation and experiment.

2. Method of experimental design using orthogonal Latin squares

On applying the method of experimental design, we first determine the number of factors to pick out in experiment and their levels. However, as the number of factors and their levels increase, the number of times of experiment also increases. In such cases, it is very effective to use the method of experimental design by means of orthogonal Latin squares, which is utilized recently in various fields. The advantages of applying orthogonal Latin squares are as follows:

1) Possible to obtain information about many factors without increasing the number of times of experiment.
2) Easy to use the confounding method and the partly practical method, without sufficient knowledge about the theory of method of experimental design. In addition, the accuracy is very high.
3) Easy to analyze the data obtained.

In orthogonal Latin squares, two-level and three-level systems are mainly used. In this paper we use three-level system. Table.1 shows 3^2 type of orthogonal Latin square, which is the smallest in the three-level ones. In the case of the three-factor and three-level, the number of times of experiment is 27 in an ordinary method, whereas by using orthogonal Latin squares it can be reduced to 9.

3. Design method

3-1 Table of the method of experimental design

The problem considered is the design of two circular patch dual frequency MSA with three layers as shown in Fig.1. We fix beforehand the configuration parameters concerning substrates as h_1=h_2=0.8mm, ε_{r1}= ε_{r2}=2.6, and choose as design factors the following three factors, that is, radius of exciting element:a_1, radius of parasitic element:a_2, and thickness of the air layer:h. Here, the initial value of each factor is regarded as level 1, and the values of ±10% to the initial values as level 2 and level 3, respectively.

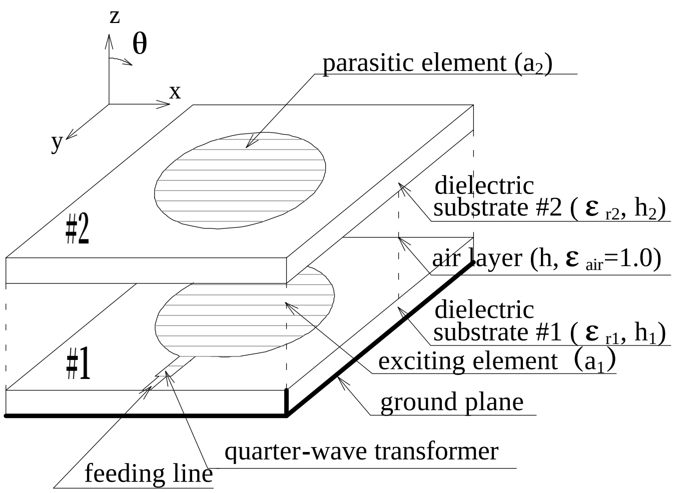


Fig.1 Configuration of MSA with three layers

Next we make the table of experimental design by using Figs.1 and 2, and compute the input impedance characteristics by the electromagnetic field simulator[4]. Then we read two frequencies corresponding to the intersection of the impedance locus in Fig.2 and their frequency interval. The table of experimental design together with the two frequencies and their interval obtained is shown in Table3. The asterisks marked in experiment number six mean that the intersection does not appear in the impedance locus.

3-2 Data analysis

From the data computed by the electromagnetic field simulator, we calculate the averages of the data in the same levels for each factor and obtain the confidence limitation after evaluating the confidence interval of the confidence coefficient 95% by using t-distribution. In the present example, all data on two frequencies f_1, f_2 (f_1<f_2) at the intersection exist inside the confidence interval. However, several data on their frequency interval Δf(=f_2-f_1) exist outside the interval. From these results, we confirm that Δf cannot be controlled by the three factors used here. Thus, we will focus attention to only two factors, i.e., f_1 and f_2.

Next, to clarify the changes of f_1 and f_2 by that of each factor, we calculate the changes of f_1 and f_2 when the value of each factor changes by 1% relative to each initial value by using the least squares method; field simulator is not used in this calculation. The results are shown in Table 4.

Next step is to adjust three factors, a_1, a_2, h, one by one, to obtain their optimum values. The first factor to be adjusted is that which brings about the largest rate of change in frequencies, and the second is of the next largest rate of change, and so on. From Table 4 we choose as the first the radius of parasitic element a_2, next the thickness of air layer h, and finally the radius of exciting element a_1.

In this manner, we adjust the value of each factor until two frequencies reach the desired values, 1.95GHz, 2.14GHz, staring from the values, 1.96GHz, 2.15GHz.

4. Experimental results

4-1 Optimization of dimensions

From the first cycle of adjustment, we obtained the results listed in the first row of Table 5, in which case both frequencies were lower than the desired ones. Then we proceeded to the second cycle of adjustment, which led to the results of the second row of Table 5. This time, the frequencies almost coincided with the desired ones.

4-2 Impedance matching

Finally, the intersection in the locus of the input impedance was shifted to the matching point by inserting a quarter-wave transformer of which line length and width are 29.6mm and 8.0mm, respectively.

4-3 Measurement results

Measurement was made for the antenna finally obtained. The return loss characteristics are shown in Fig.3. Two resonant frequencies f_L,f_H (f_L<f_H) and four frequencies of -10dB points are shown in Table 6. Both resonant frequencies almost agree with the desired ones. As regards the four frequencies of -10dB points, both upper frequencies f_{H1} and f_{H2} are slightly lower than the desired. Figure 4 shows the radiation patterns of E and H planes at 1.95GHz and 2.14GHz. The radiation patterns at both frequencies are practically symmetrical and 3-db beam width is around 60 to 70degs. The cross-polarization level is below -20dB for E and H planes at both frequencies. Finally Fig.5 shows the gain characteristics. The gains at both frequencies are nearly equal, the values being about 8.5dBi.

5. Conclusions

Owing to the usefulness of data analysis and design using orthogonal Latin squares, the adjustment of parameters of only twice was sufficient to design the MSA with multi-layer configurations.

From the present example we are confirmed that the experimental design by use of orthogonal Latin squares works very effectively in designing antennas with multiple configuration parameters.

References

[1] Daniel S. Weile and Eric Michielssen, “Genetic Algorithm Optimization Applied to Electro-magnetics: A Review,” IEEE Transaction on Antennas and Propagation, Vol. 45, No. 3, March 1997

[2] G.Taguchi, Design of Experiments, Maruzen, Tokyo, 1976

[3] Ootaki, Hirakuri, Nakazato and Kawasaki, Method of experimental design for Quality control JUSE. Press, Ltd

[4] Boulder Microwave Technologies, Inc, Ensemble

Table 1: 3^2 type of orthogonal Latin squares

row No. / line No.	1	2	3	4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	3	2
5	2	2	1	3
6	2	3	2	1
7	3	1	2	3
8	3	2	3	1
9	3	3	1	2

Table 2: Factors and levels

factor	level
A: radius of exciting element a_1	1: 29.0[mm], 2: 31.9[mm], 3: 26.1[mm]
B: radius of parasitic element a_2	1: 35.0[mm], 2: 38.5[mm], 3: 31.5[mm]
C: thickness of air layer h	1: 4.50[mm], 2: 4.95[mm], 3: 4.05[mm]

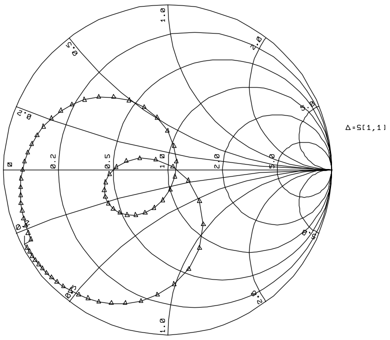


Fig.2 Input impedance characteristics (initial parameter)

Table 3: Table of experimental design and calculation by a simulator (f_1<f_2)

exp.No.	factor [mm]			Calculated data [GHz]		
	A	B	C	f_1	f_2	Δf
1	29.0	35.0	4.50	1.96	2.15	0.19
2	29.0	38.5	4.95	1.74	1.95	0.21
3	29.0	31.5	4.05	1.74	1.95	0.21
4	31.9	35.0	4.05	2.05	2.11	0.06
5	31.9	38.5	4.50	1.81	1.98	0.17
6	31.9	31.5	4.95	****	****	****
7	26.1	35.0	4.95	1.90	2.10	0.20
8	26.1	38.5	4.05	1.74	1.93	0.19
9	26.1	31.5	4.50	2.15	2.35	0.20

Table 4: Two frequencies f_1,f_2 changes for each factor [GHz/%]

Factor	f_1	f_2
A: radius of a exciting element a_1	0.0000	-0.0041
B: radius of a parasitic element a_2	-0.0221	-0.0186
C: thickness of the air layer h	-0.0098	-0.0044

Table 5: Results of adjustment of parameters

	a_1[mm]	a_2[mm]	h[mm]	f_1[GHz]	f_2[GHz]
First	29.07	35.19	4.49	1.928	2.127
Second	29.30	34.94	4.46	1.957	2.140

Table 6: Measurement results of two resonant frequencies and -10dB points [GHz]

	Resonant frequencies		-10dB points			
	f_L	f_H	f_{L1}	f_{L2}	f_{H1}	f_{H2}
Measured value	1.952	2.127	1.928	2.017	2.082	2.157
Desired value	1.95	2.14	1.92	1.98	2.11	2.17

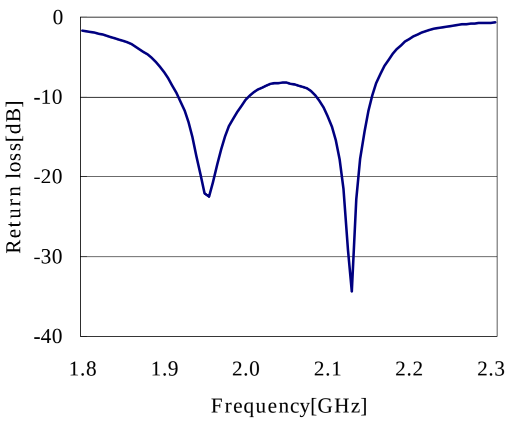


Fig.3. Return loss characteristics

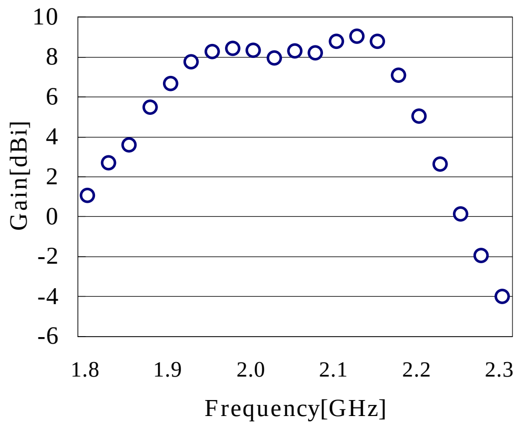
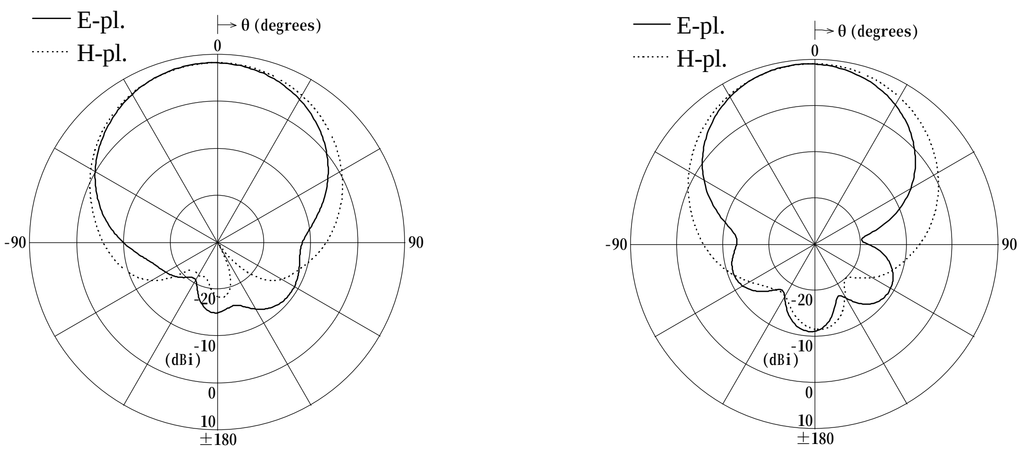


Fig.5. Gain characteristics



(a) f=1.95[GHz]

(b) f=2.14[GHz]

Fig.4. Radiation patterns (E and H plane)